Contra Rotating Propellers (CRPs)

Green Deal Validation

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MARIN

KONINKLIJKE VERENIGING VAN NEDERLANDSE REDERS

Ministerie van Infrastructuur en Waterstaat

Ministerie van Economische Zaken en Klimaat

Description

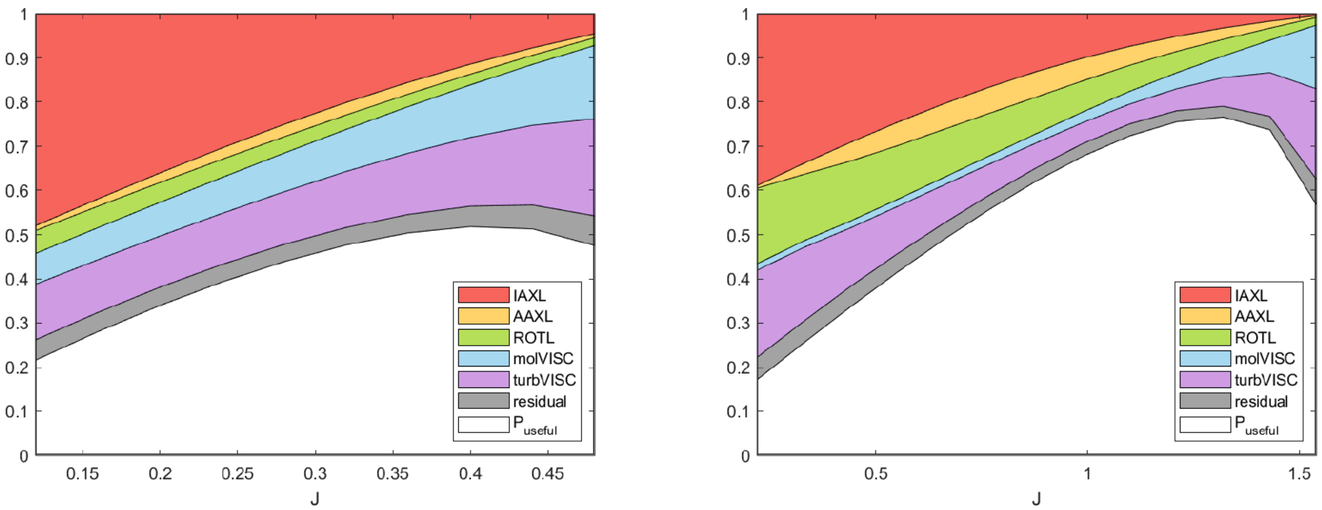
Contra-rotating propellers (CRPs) have already been in use as long as single propellers. A CRP has two propellers placed behind each other, rotating in opposite direction. The rotational losses from the front propeller are recovered by the rear propeller.

Working principles

To understand the potential benefits of a CRP compared to a single propeller, the losses of a propeller need to be assessed in more detail. The losses of a propeller can typically be described in four components, following Schuiling & Terwisga (2016):

Ideal axial loss (IAXL)	**Addition axial loss (AAXL)**	**Rotational loss (ROTL)**	**Viscous loss (VISC)**
The most effective way to produce a certain amount of axial momentum is by accelerating a large volume flow by only a small amount, which requires a large propeller diameter. This is independent of a CRP	The radial loading variation and finite number of blades give inequalities in the induced axial momentum. Using a CRP, the uniformity of the axial flow is improved, both in time and space.	A rotating propeller induces a rotating motion in its wake which is not effective in propelling the ship. This reduces the efficiency of the propeller. A well-designed CRP almost fully recovers this energy.	Energy is dissipated due to friction. The best way to suppress viscous losses is to lower the speed through water by lower rotation rate. For a CRP, the corresponding increase in rotational loss is recovered by a CRP.

The losses are visualized in the figure below for a low pitch (left) and high pitch (right).The plots give the efficiency as function of advance coefficient J. The rotational losses and additional axial losses increase with pitch, while the viscous losses decrease with pitch.



Example of an open water diagram, showing the efficiency and description of losses. From Manting (2019)

Balancing and recovery of energy losses

In the design of a single propeller the main particulars are chosen that offer the best balance between the losses for optimum behind-ship efficiency. This defines thus the number of blades, the blade area ratio, the diameter and the pitch of the propeller.

In the case of a CRP it is possible to increase the pitch of the propeller without penalty on the rotational loss or the additional axial loss. The rotation rate and thus the viscous loss decrease without increasing the rotational loss. A CRP really becomes attractive if the rotation rate can be lowered significantly or if the allowed diameter is smaller than optimum for a single propeller.

A check based on the diameter and rotation rate compared to a single propeller variant could already reveal whether the potential efficiency gains of the CRP are utilized.

Market readiness

CRP systems are widely available, especially for the lower power segment for outboard motors, river cruisers and yachts.

For the higher power segment often the limitations to the engine torque and/or mechanical challenge prevent widespread application. Usually, additional lead time is required for design and development due to the complexity of the installation.

Configurations

CRPs are mainly applied in three different configurations:

1. The two propellers are placed directly after each other with hollow shafts.
2. Both propellers are installed on a pod:
   a. One propeller at each side of the pod. This provides a difficult wakefield to rear propeller and part of rotation is already recovered (with higher losses) by the strut.
   b. Pulling pod with the propellers at the front. Due to high velocity and no recovering effect, the resistance of the pod significantly influences the total efficiency.
   c. Pushing pod with both propellers at the rear. The front propeller encounters a wakefield from the strut and the strut encounters a suction effect.
3. The rear propeller is integrated in the rudder or placed on a pod with sufficient steering capability to replace the rudder.

Besides efficiency benefits, CRPs are also applied on foiling boats and torpedoes due to the zero net torque that the propellers exert (no wheel effect).

Application

- CRPs are mostly applied for new builds. Retrofitting a single propeller for an CRP is often not feasible due to complicated mechanical installation and the high investment costs.
- CRPs usually have short shafts due to increased complexity with very long shafts that could be present for twin-screw arrangements as used on patrol vessels, frigates and some ferries and cruise vessels.
- CRPs are not suited for dredgers, tugs and fishing vessels. These ships have ducted propellers that are superior in pulling performance.
- CRPs are applicable to all kinds of vessels, including general cargo vessels, offshore supply vessels, crew tenders, super yachts, cruise vessels, container ships, bulk carriers and tankers.

General Cargo	Tug	Offshore supply	Crew tender	Dredger	Super Yacht	Cruise	Container ship	Bulker	Tanker
+	-	+	+	-	+	+	+	+	+

Usually the diameter of the rear propeller is selected to be smaller to avoid adverse interference with the tip vortices of the front propeller. However, this appears not to be a rule of thumb. In terms of power savings, a CRP is not so sensitive to the choice of number of blades as a single propeller. There is also no clear hydrodynamic benefit to choose the front or the rear propeller with a larger number of blades. For noise emission, usually the rear propeller has more blades. The two propellers have different numbers of blades to prevent resonance and vibration problems.

Emmision reduction potential

The optimum CRP rotates extremely slowly to minimise viscous losses. Typically, the rotation rates are 35 to 50% lower than that of the single propeller. Then, the CRP would provide savings of 12 to 15% in required power at the propellers, according to the results of systematic model tests with CRPs. Also the bollard pull is usually 10 to 20 % larger. Usually, the required torque becomes not feasible.

For equal rotation rate compared to a single propeller, savings up to only 3% to 7% are realistic compared to a single propeller. The optimum propeller diameter would then be about 10% to 15% smaller than the single propeller.

Apart from the reduction in required power, a CRP has no further benefit in terms of pollutants.

Propeller-hull interaction

Lowering the rotation rate is a general rule in propeller design if a larger diameter can be installed. At these low rotation rates, however, the power savings of a CRP are larger, the torque (per propeller) is lower and the diameter is more suited to the draught and aft-body of the ship. However, with optimized integration into the ship the large single propeller might gain on hull efficiency, coming very close to the CRP system in terms of overall efficiency.

The hydrodynamic power savings from a CRP should always be assessed together with the design and integration into the ship and the potentially increased losses from shaft, gearbox and hull efficiency. A rudder or strut behind a single propeller may recover about half of the rotational losses. Therefore, a rudder behind a CRP has more resistance. Gearbox efficiencies may have dominant influence on the total emission reduction, depending on the type of application and the reduction ratio.

Ballast conditions or ships with large shaft inclination might give additional savings of 3% due to the reduction of the additional axial losses due to tangential inflow.

Benefits from different rotation rates of the front and rear propeller are sometimes claimed, but are often limited to about 1% and are therefore normally not considered due to additional complexity.

Operational aspects

Vulnerability	Shallow water	Manoeuvring	Redundancy	Ease of control
Increased, due to complexity of gearbox, shafts, seals and bearings	Ships can be designed with smaller draught	No real difference with single propeller	Potentially improved, if the propellers are driven independently	No real difference with single propeller

Costs

Payback times are estimated medium-long 10 to 15 years, although some manufacturers claim shorter times. The increased risks and costs for a CRP often prevent the application for merchant vessels.

Investment	Operational	Indirect
Complex gearbox Complex shafting system Two propellers instead of one More time required for design and installation	Additional maintenance Decreased fuel costs	Increased weight and required space of the installation

Development prospects

CRPs are already well proven. CRP systems have been in operation for years already. New developments are expected in

- high efficiency gear boxes and more reliable shafting solutions.
- new types of electric motors with higher torque limits and lower rotation rates that could drive CRPs efficiently without gearbox.

References

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